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COMPARISON OF CONDENSATION NUCLEUS COUNTER, ELECTRICAL AEROSOL ANALYZER, AND CARBON MONOXIDE WASHOUT DATA FOR TWO COLLECTIVE SHELTERS

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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Data from a condensation nucleus counter indicate that washout of a propane-flame-produced aerosol from a chemical defense groundcrew shelter can be represented as an exponential decay with a halftime of 1.5 to 2 min depending on location in the shelter. Data from another shelter is more complex . The condensation nucleus counter data were augmented by particle size data from an electrical aerosol analyzer and by carbon monoxide data. The halftimes calculated from carbon monoxide, condensation nucleus counter, and electrical aerosol analyzer particle count data from one shelter are in general agreement. Data from the other shelter indicate that particle agglomeration is significant, and that total particle volume and carbon monoxide data give halftimes about twice as long as particle count data. Condensation nucleus counter data can be used to determine washout halftimes only when particle agglomeration is not significant with respect to washout.

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COMPARISON OF CONDENSATION NUCLEUS COUNTER, ELECTRICAL AEROSOL ANALYZER, AND CARBON MONOXIDE WASHOUT DATA FOR TWO COLLECTIVE SHELTERS

INTRODUCTION

Data from a condensation nucleus counter (CNC), TSI Model 3020, indicate that washout of a propane-flame-produced aerosol from the chemical defense groundcrew collective shelter can be represented by a one-compartment model with a halftime of 1.5 - 2 min, excluding off-gassing booths [1]. The aircrew collective shelter CNC data indicate a more complex relationship, particularly in the off-gassing booths [1]. Because of the extreme importance of adequately predicting air quality in shelters, CNC data were augmented by particle size distribution data from an electrical aerosol analyzer (EAA), TSI model 3030, and by carbon monoxide (CO) data.

Particle size distributions or CO data are needed because the CNC measures particle number, only. If CNC data show a decrease in particle number, it is not possible to say definitively whether the decrease is due to washout or particle agglomeration. However, it is possible to predict the range of particle concentration for which particle agglomeration is important. If particle agglomeration is occurring, the mass of material in the aerosol is decreasing less rapidly than would be predicted assuming that a decrease in the number of particles is due to particle washout alone.

The half-lives calculated from CO, CNC, and EAA count data from the groundcrew shelter are in general agreement (1.5 - 2 min for the locations studied). Data from a booth in the aircrew shelter, however, indicate that particle agglomeration is significant when particle concentration exceeds 1.0E5/cm^3, because half-lives calculated from particle count data are shorter than half-lives determined from CO data. Total particle volume and CO data give half-lives of 10 min or more for the off-gassing booths in the aircrew shelter.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Groundcrew Shelter

The floor plan of the groundcrew shelter is shown in Figure 1. Ventilation is provided by two Industrial Design Laboratories fan filter assemblies (part no. FFA 580-1000), which provide 1800 cfm. The ventilation air was determined to be essentially free of particles in the size ranges of the CNC and EAA measurements. Particle measurements were made in the area labeled vapor hazard area (VHA). The equipment used in the groundcrew shelter is shown in Figure 2.

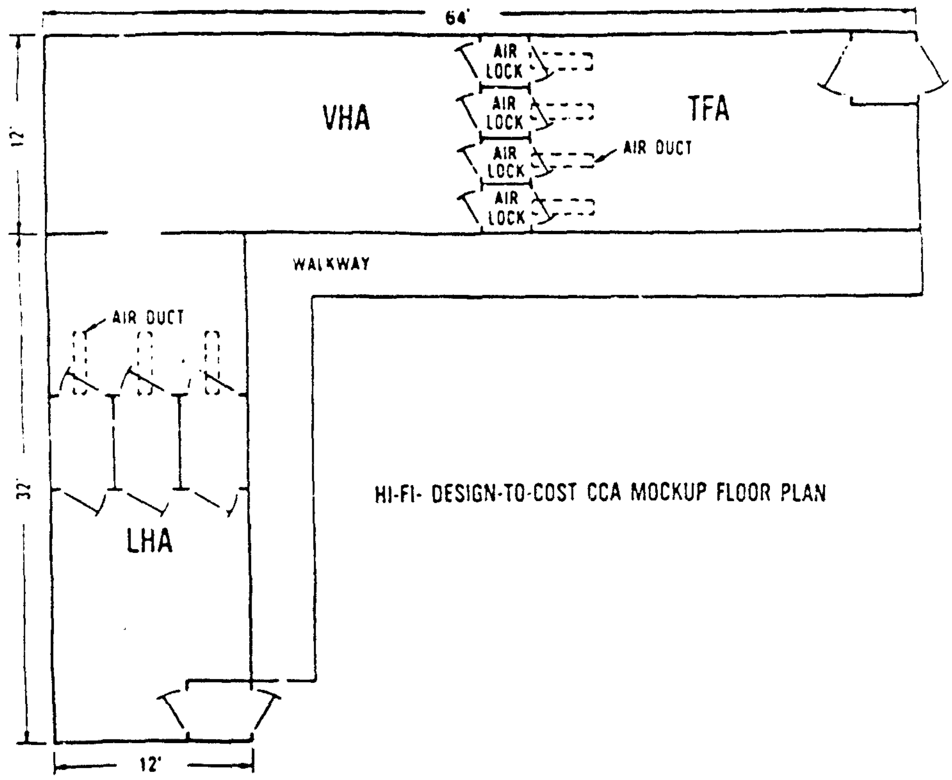

Figure 1. Groundcrew collective shelter.

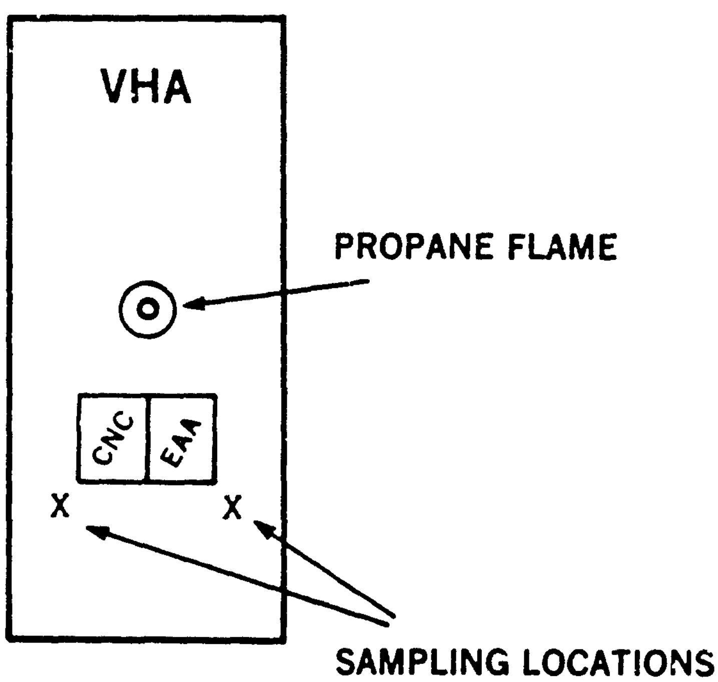

Figure 2. Sample locations and aerosol source.

Particle count data were taken using a TSI Model 3032 continuous-sampling condensation nucleus counter. Total particle count and particle volume data were obtained using a TSI Model 3030 electrical aerosol analyzer. The CNC and EAA sampled through tygon tubing .64 cm ID and 0.9 m long (¼ in. ID, 3 ft long) placed about 7.6 cm (3 in.) apart, approximately 1.7 m (5-½ ft) above the floor. The design principles, capabilities, and limitations of both the CNC and EAA have been presented in the open literature (e.g., 2-10). The CO data were obtained in a separate experiment. The characteristics of the CO measurement device are described in the next section.

Aircrew Shelter

The floor plan of the aircrew shelter is shown in Figure 3. Ventilation is provided by two Industrial Design Laboratories fan filter assemblies, which provide 755 L/sec (1600 cfm.) The ventilation air was determined to be essentially free of particles in the size range of the CNC and EAA measurements. The measurements were made from off-gassing booth 1. The first four data samples were EAA and CNC data only. Data for the remaining two samples included CO washout data in addition to CNC and EAA data. Particle and CO samples were taken through 0.9m-long (3-ft-long) tygon tubing from a height of about 1.5 m (5 ft.)

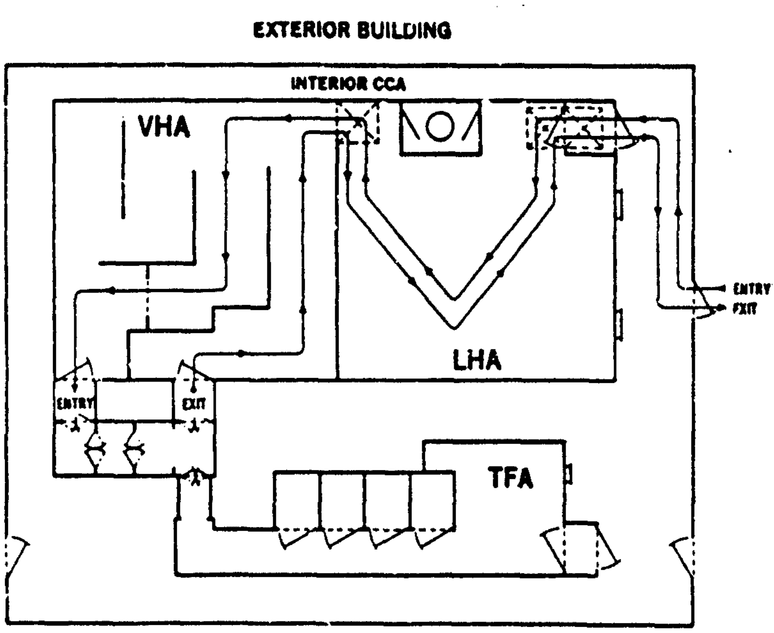

Figure 3. Off-gassing booth, aircrew collective shelter.

Carbon monoxide data were collected using a 2000 Series Ecologizer model CO analyzer manufactured by Energetics Science Inc. All data were taken with 50/100 ppm instrument (S/N F1720). The instrument was set on the 100 ppm scale for aircrew CO data. Prior to use, the analyzers were calibrated using a 25 ppm CO-in-air gas standard. Instrument sensitivity, as given by the manufacturer's specification sheet, is 0.5% full scale with a precision of 1% full scale.

Carbon monoxide can be considered an inert gas because its chemical half-life in the atmosphere is several hours. Thus, half-lives derived from CO data can be considered to be the true half-life for washout.

RESULTS AND DISCUSSION

Data collected by all instruments were subjected to a least-squares fit to the equation:

$$\ln y = \ln a - bt \tag{1}$$

A half-life was calculated as:

$$t_{\frac{1}{2}} = (\ln 0.5)/b \tag{2}$$

for one or more segments of the concentration data curves. The calculated half-lives are shown in Tables 1 and 2.

TABLE 1. GROUNDCREW SHELTER HALF-LIVES

	CO (min)	CNC[a] (min)	EAA[b] (min)
17 Apr 84 Run 1	-	1.7	-
t = 2.5 to 16.5	-	-	1.6[c]
t = 0 to 10	-	-	1.5
17 Apr 84 Run 2			
t = 2.5 to 15.5	-	1.9	-
t = 0 to 25	-	-	1.6[c]
t = 0 - 10	-	-	1.8
24 Jul 84 Runs 1-3	1.5	-	-
t = 0 to 6	1.6	-	-
t = 0 to 5	1.6	-	-

[a] Points above 1.0E3 particles/cm^{-3}
[b] All measured points.
[c] Interval with least variance.

TABLE 2. AIRCREW SHELTER, BOOTH 1 HALF-LIVES

	CO (min)	CNC (min)	EAA N (min)	EAA VOL (min)
18 Apr 84 Run 1				
t = 0 to 25	-	-	5.6	12.7
t = 17 to 25.5	-	-	9.0	10.4
t = 17 TO 30	-	7.7	-	-
18 Apr 84 Run 2				
t = 0 to 25.5	-	-	5.8	12.4
t = 19 to 25.5	-	-	7.6	11.7
t = 18 to 30	-	8.0	-	-
18 Apr 84 Run 3				
t = 0 to 25.5	-	-	6.5	10.6
t = 18 to 25.5	-	-	8.1	11.7
t = 18 to 30	-	8.2	-	-
18 Apr 84 Run 4				
t = 0 to 25.5	-	-	5.7	12.0
t = 18 to 25.5	-	-	7.3	8.7
t = 18 to 30	-	7.5	-	-
19 Apr 84 Run 1				
t = 0 to 25.5	-	-	6.0	13.6
t = 16 to 25.5	-	-	7.3	17.6
t = 16 to 40	11.3	8.8	-	-
t = 0 to 43.5	11.3	-	-	-
19 Apr 84 Run 2				
t = 0 to 25.5	-	-	6.8	13.0
t = 19 to 25.5	-	-	8.3	16.8
t = 19 to 40	11.8	9.6	-	-
t = 0 to 49.5	12.3	-	-	-

Characteristics time scales (t_c) for particle agglomeration in a polydisperse aerosol are shown for several values of particle concentration in Table 3. They are calculated from agglomeration coefficients given by Hinds (3). At 1.0E7/cm^3 particles, particle-particle interaction occurs about once a minute, while at 1.0E6 particles/cm^3, particle-particle interaction occurs once approximately every 10 min. These estimates and calculated half-lives can be used to predict whether particle agglomeration will affect measurements of particle count.

TABLE 3. CHARACTERISTIC TIME SCALES FOR PARTICLE AGGLOMERATION IN A POLYDISPERSE AEROSOL*

Concentration	Time Scale
1.0E7	1 min
1.0E6	10 min
1.0E5	1 hr, 40 min
1.0E4	hours

*Count median diameter = 0.2 μm, and geometric standard deviation = 2.5 μm.

We can compare the characteristic time scale for agglomeration and the apparent half-life for washout. When $t_c << t_{\frac{1}{2}}$ agglomeration occurs rapidly relative to washout, a measured decrease in the number of particles would be due mainly to agglomeration. When two particles agglomerate, the particle count decreases, but particle mass is unaffected. If $t_c >> t_{\frac{1}{2}}$ particle number decrease due to agglomeration is less important compared to particle decrease due to washout. When $t_c \sim t_{\frac{1}{2}}$ both agglomeration and washout are important in determining particle count.

Groundcrew Shelter

Figure 4 shows CNC and EAA particle count data as the particles created by the propane flame are removed from the groundcrew shelter. The half-lives determined by CNC data are 1.7 and 1.9 min; the half-lives determined by EAA data are 1.5 and 1.8 min. Total volume data tend to confirm exponential decay, although half-lives were not calculated because of the substantial scatter in the total volume data.

Figure 4 also shows CNC and EAA count data, decreasing exponentially for 16 min. After 16 min the rate of decrease changes. The point of change corresponds to the CNC's shift from optical to single particle counting mode. There is also a corresponding change in the EAA data, but no instrumental reason to explain the change in slope. The reason for the change in slope is unknown.

Figure 5 shows CO washout data for 5- and 6-min periods. As shown in Table 1, calculated half-lives for all the groundcrew facility data fall between 1.5 and 1.9 min. The agreement among the three types of data is consistent with little particle agglomeration; $t_c >> t_{\frac{1}{2}}$.

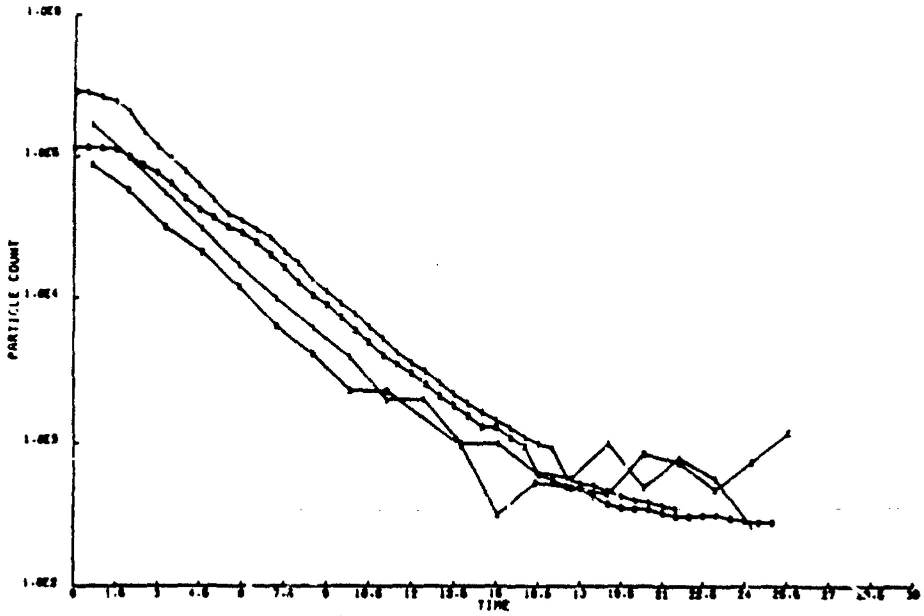

Figure 4. Groundcrew collective shelter CNC and EAA data for runs 1 and 2.

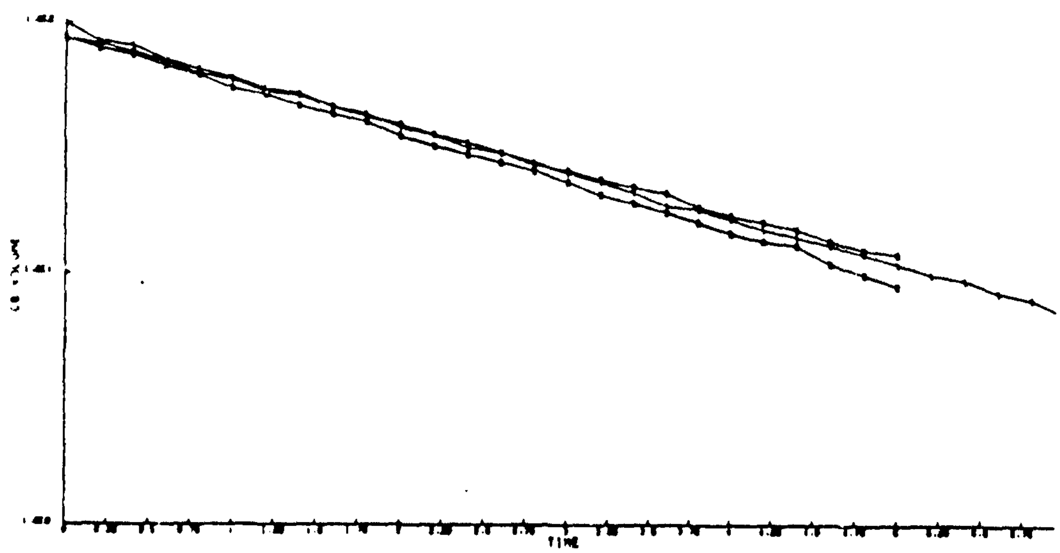

Figure 5. Groundcrew collective shelter CO data for runs 1-3.

Aircrew Shelter

Figure 6 shows CNC particle data for the aircrew shelter off-gassing booth. The data curves appear to be divided into four segments, S1, S2, S3, and S4. In segment S1, where particle concentration is > 1.0E6, agglomeration is clearly important in decreasing particle count ($t_c \sim t_{1/2}$). Segments S2 and S3, which correspond to particle concentrations between 1.0E5 and 1.0E6, decrease less rapidly than S1 due to decreased agglomeration, with S4 corresponding to particle concentrations below 1.0E5, for which agglomeration becomes less important. Calculated half-lives for segments S1 - S4 are listed in Table 4.

TABLE 4. BOOTH 1 HALF-LIVES (MINUTE) BY SEGMENT

Segment	Run 1	Run 2	Run 3	Run 4
1	0.47	0.34	0.65	0.48
2	3.1	2.9	3.0	2.8
3	6.4	7.1	6.5	7.0
4	7.7	8.0	8.2	7.5

Figure 7 shows EAA particle count data for runs 1-4 on 18 Apr 84. The effect of agglomeration at higher particle concentrations (>1.0E6) is evident in the data. The effect of agglomeration is less apparent at lower particle concentrations, but detectable in the departure of the data from a straight line.

Figure 8 shows both EAA and CNC data for runs 1 and 2 on 19 Apr 84. The CNC data shows only three segments, corresponding to S2, S3 and S4 in Figure 6. The EAA data also depart from the expected straight line, although all four data curves are more linear below a particle count of about 1.0E5.

Figure 9 shows EAA total particle volume data for six runs.

Total particle volume is calculated as:

$$V = (\pi/6) \sum_{i=1}^{m} n_i \, d^3_i \tag{3}$$

where:

n_i = the number of particles in the ith interval.

d_i = the mean diameter of the particles in the ith interval

m = the number of intervals.

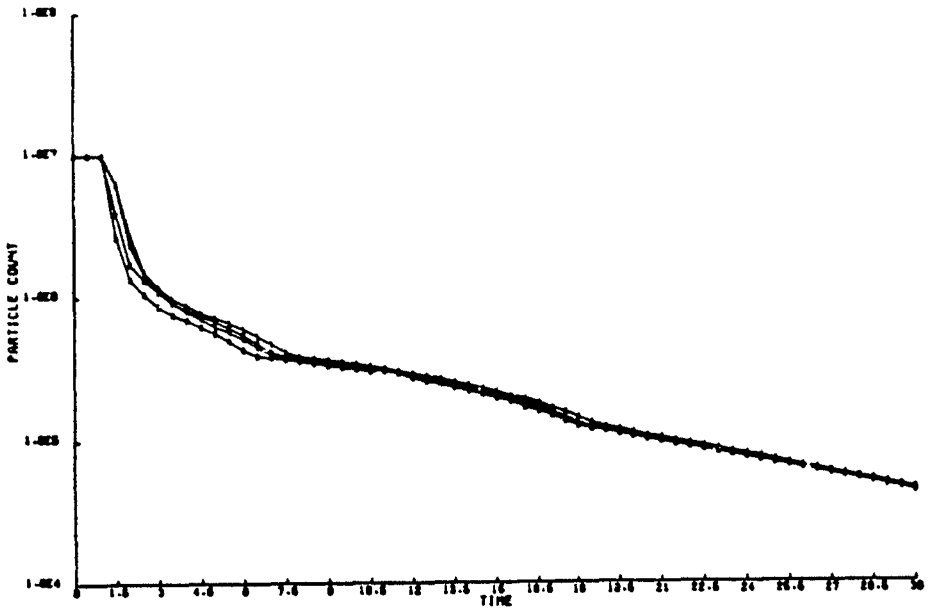

Figure 6. Aircrew collective shelter CNC data for runs 1-4 (18 Apr 84).

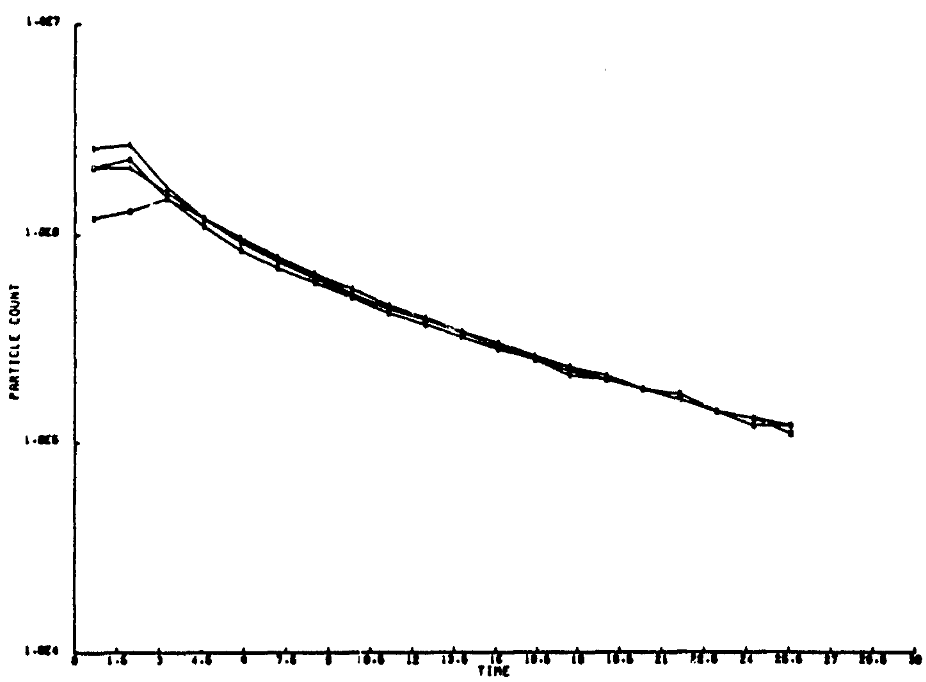

Figure 7. Aircrew collective shelter EAA data for runs 1-4 (18 Apr 84).

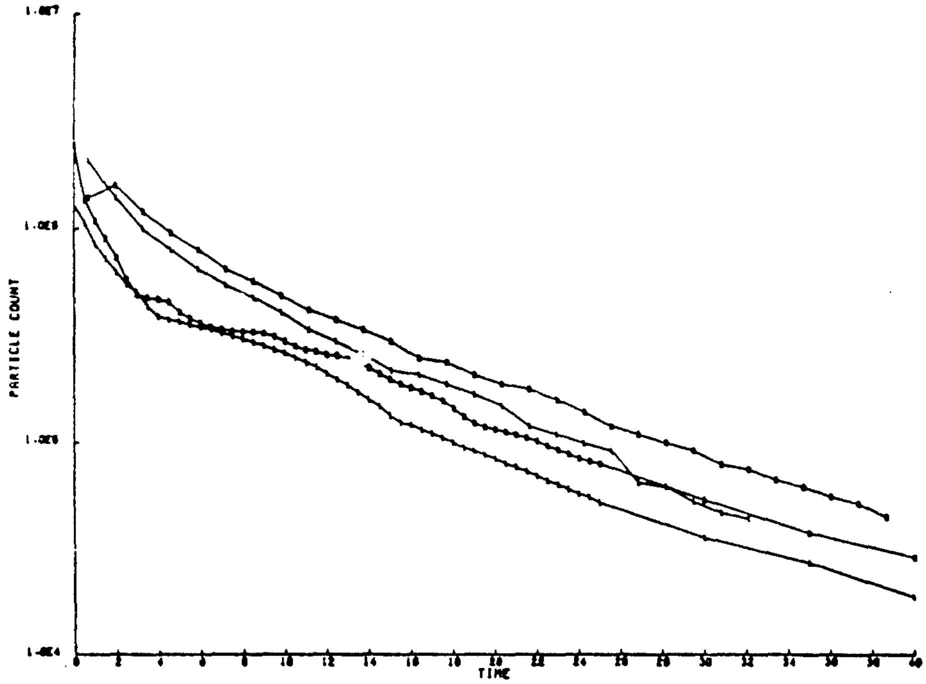

Figure 8. Aircrew collective shelter EAA and CNC data for runs 1 and 2 (19 Apr 84).

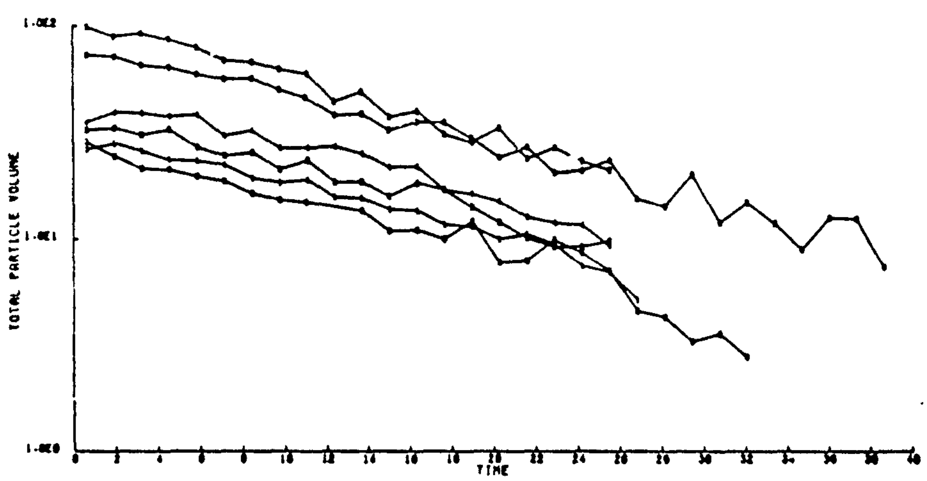

Figure 9. Total particle volume EAA data for runs 1-4 (18 Apr 84) and runs 1 and 2 (19 Apr 84) for aircrew collective shelter.

Total particle mass is total particle volume multiplied by particle density, assumed to be constant for all particles. Particle number decreases in one size interval due to agglomeration appear as increases in a larger size interval (i.e., mass is conserved).

Half-lives calculated from volume data range from 8.7 to 17.3 min with geometric mean of 12.3 min for the 0-25.5 min segments (Table 2). Figure 10 shows CO data for runs 1 and 2 on 19 Apr 84. Calculated CO half-lives range from 11.3 to 12.3 min.

In general, the aircrew shelter data half-lives calculated from either CNC or EAA count data are about half the half-lives calculated from CO or particle volume data. The discrepancy indicates that particle agglomeration is contributing to the observed decrease in the number of particles. The aerosol volume data, however, take into account particle growth.

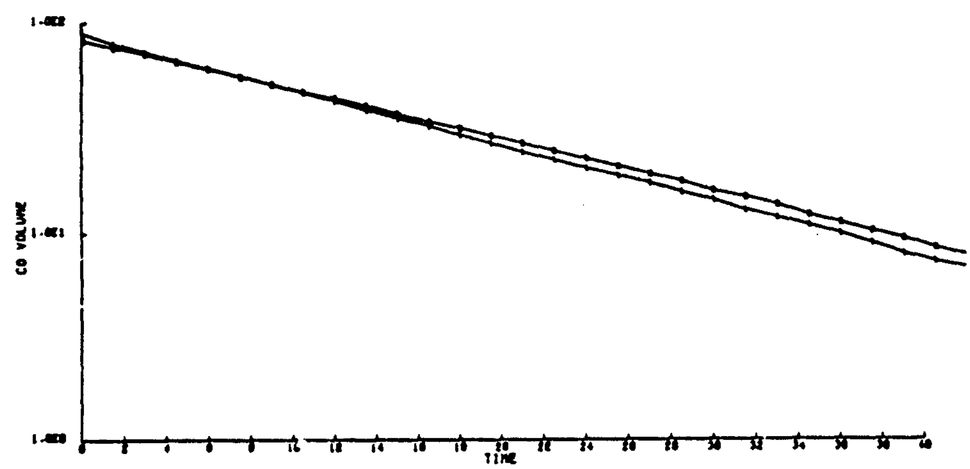

Figure 10. Aircrew collective shelter CO data for runs 1 and 2 (19 Apr 84).

CONCLUSIONS

From CNC, EAA, and CO data, the half-life of particles due to washout is 1.5 to 2.0 min for the location studied in the groundcrew shelter.

At the particle concentrations encountered in the groundcrew shelter, particle agglomeration is not an important factor in observed particle decrease.

From the agreement between EAA volume data and CO data, the half-life of particles due to washout is 10-15 min in the off-gassing booth of the aircrew shelter.

In this application, CNC particle decrease data can be used to calculate half-lives for washout only when particle concentration is less than 1.0E5 cm^{-3}.

In general, the particle concentration range for which agglomeration influences calculated washout half-lives can be determined by comparing t_c and $t_{½}$. When $t_c \ll t_{½}$, agglomeration is important; when $t_c \gg t_{½}$, agglomeration has little effect on observed particle half-lives.

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